MINERAL INCLUSIONS IN DIAMONDS FROM THE PANDA KIMBERLITE, SLAVE PROVINCE (CANADA)

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INTRODUCTION

88 inclusion bearing diamonds from the Panda kimberlite were selected to study the composition of the lithospheric and sublithospheric mantle beneath the Slave craton. The Panda pipe, located in the Lac de Gras area, N.W.T., is part of a Cretaceous-Tertiary kimberlite domain (Heaman and Kjarsgaard, 2000) and hosts Canada's first diamond mine.
The inclusions were analyzed using electron (major elements) and ion micro probes (trace and ultra-trace elements).

MAJOR ELEMENTS

Major element data for the mineral inclusions show that the majority of diamonds (82%) belong to the peridotitic suite.
The composition of the *peridotitic* garnets is characterized by CaO contents >3.0 wt%, with five samples falling into the field of Ca-saturated, lherzolitic garnets (Fig.1). This suggests formation in an only moderately depleted environment, without indications for low Ca-harzburgitic and dunitic sources.

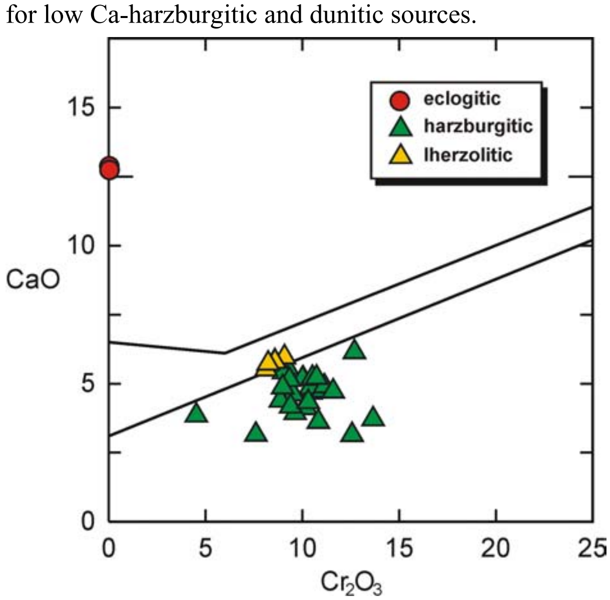

Figure 1: CaO versus Cr_2O_3 plot for garnet inclusions in diamonds from Panda. Compositional field for lherzolitic garnets from Sobolev et al. (1973).

Average Mg-numbers for olivine (92.5) and orthopyroxene (94.2) also are not indicative of ultra-depleted source rocks. Further recovered peridotitic minerals comprise magnesiochromites and Fe-Ni monosulfides with major element compositions typical for inclusions in diamonds worldwide. An unidentified phase with low silicon content (28.2 wt% SiO_2) was found as part of a four-phase intergrowths with garnet, olivine and orthopyroxene.
Mineral inclusions of the *eclogitic* suite are rare in the Panda diamonds, similar to other kimberlites within the Ekati property (Chinn et al., 2001) and Snap Lake (Pokhilenko et al., 2001) but in contrast to DO27 (Davies et al., 1999). Two eclogitic garnets with identical composition could be recovered from one diamond (Fig.1). The garnets are characterized by high Ca (12.8wt% CaO) and Ti contents (0.9 wt% TiO_2). Only one clinopyroxene with a jadeite component of 20 mol% was found, forming a touching pair with rutile. Two eclogitic sulfides were found, one Fe-monosulfide with minor amounts of Ni, Cu and Co. The second sulfide shows strong exsolution patterns, probably caused by the exsolution of bornite and chalcopyrite from a former copper rich (~41 wt% Cu) mono-sulfide solid solution.

GEOTHERMOBAROMETRY

The composition of eight non touching garnet-olivine inclusion pairs was used to estimate temperatures of diamond formation by applying the thermometer of O'Neill and Wood (1979) and O'Neill (1980). The resulting average temperature of 1142°C is similar to the average temperature of ~1150°C for diamond formation worldwide. In accordance to that is the average temperature of 1159°C, calculated for magnesiochromite inclusions from Panda using the empirical thermometer of Ryan et al. (1996).
The temperature estimates for the formation of the Panda diamonds agrees with P-T results calculated for garnet-orthopyroxene inclusion pairs in diamonds from the Snap Lake kimberlite (data from Pokhilenko et al., 2001), using the barometer of Brey and Köhler (1990) and the thermometer of Harley (1984). These data appear to indicate diamond formation in the central and

southern Slave along a geothermal gradient of 40-42 mW/m^2 (surface heat flow), similar to other cratons worldwide.
Two touching garnet-orthopyroxene inclusion pairs from Panda diamonds appear to have equilibrated at lower temperatures corresponding to a geothermal gradient of around 37 mW/m^2 (Fig 2).

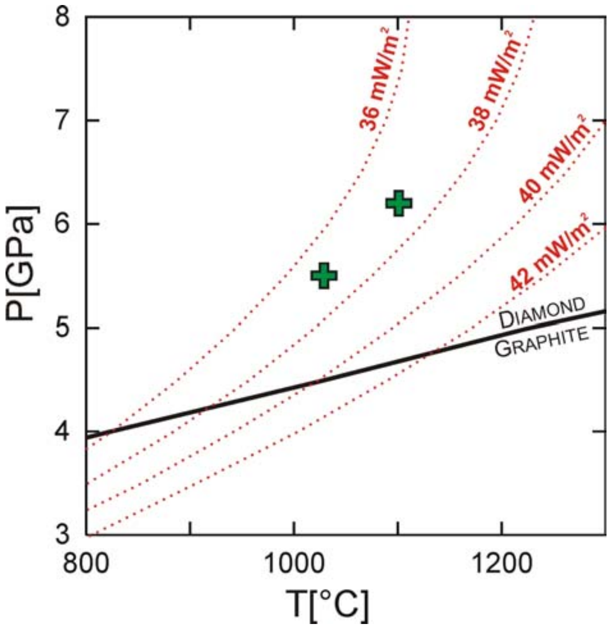

Figure 2: Calculated P-T conditions for touching garnet-orthopyroxene inclusion pairs from Panda diamonds. The dotted lines indicate conductive geotherms for various surface heat flow values (calculated after Pollack and Chapman, 1977)

A similar low Cretaceous to Tertiary palaeo-geotherm of around 38 mW/m^2 was found for peridotite xenoliths from the Lac de Gras area (Griffin et al., 1999).
The apparent discrepancy between the geothermal gradient during diamond formation and the geotherm at the time of kimberlite emplacement possibly relates to in part rather low aggregation levels of nitrogen impurities within a number of Panda diamonds (Fig.3). A drop in ambient temperature by at least 100°C soon after diamond formation can explain the low nitrogen aggregation levels. .

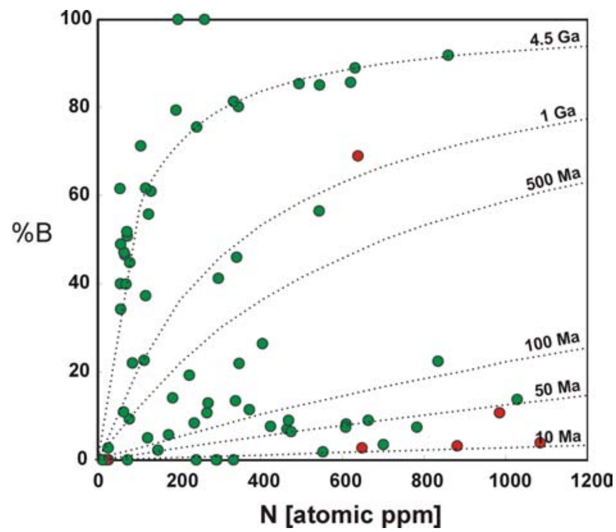

Figure 3: Aggregation level (percentage of higher aggregated B-center relative to the A-center) versus nitrogen concentration in diamonds from Panda. Dotted lines are isochrones for the residence time of diamonds at an assumed temperature of 1150°C. Green dots: peridotitic, red dots: eclogitic diamonds.

SUBLITHOSPHERIC DIAMONDS

Beside the lithospheric inclusions three Panda diamonds contain phases that indicate an origin from the lower mantle. The characteristic inclusion phase in these diamonds is ferropericlase. In one case ferropericlase is associated with CaSi-perovskite in another case with a SiO_2-phase, which was probably formed as stishovite. Another diamond contained a touching inclusion pair of ferropericlase and MgAl-spinel (with minor amounts of Fe and Cr). This spinel probably originated as ε-spinel, a lower mantle phase experimentally predicted for corundum saturated bulk compositions (Liu, 1978).
Similar to previous studies (e.g. Davies et al., 1999) all diamonds with an assumed lower mantle origin have an irregular crystal shape in combination with nitrogen concentrations below detection (Type II diamonds).

TRACE ELEMENT COMPOSITION

REE concentrations were determined for ten peridotitic garnets. The resulting chondrite normalized REE patterns indicate a general agreement with the major element composition. Lherzolitic garnets show MREE-HREE enriched or slightly sinusoidal REE pattern (Fig.4), whereas harzburgitic garnets derived from depleted lithologies show sinusoidal shapes (Fig.5).

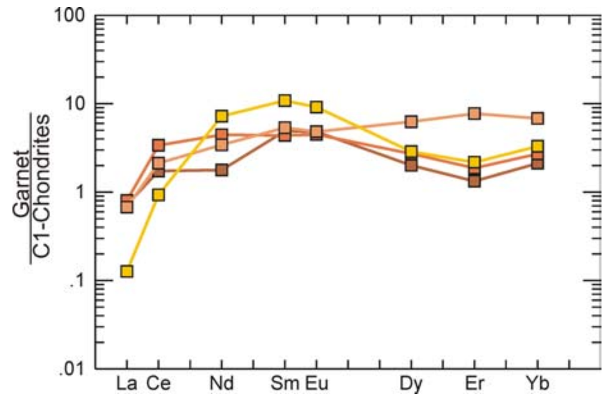

Figure 4: REE concentration in lherzolitic garnet inclusions from Panda diamonds, normalized to CI-chondrite composition

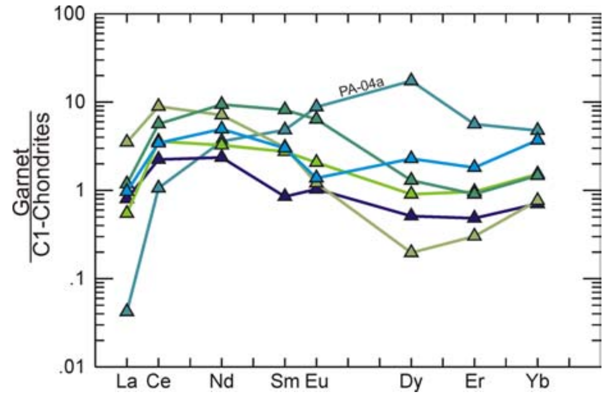

Figure 5: REE concentration in harzburgitic garnet inclusions from Panda diamonds, normalized to CI-chondrite composition

Only one harzburgitic garnet (PA-04a in Fig.5) shows an overall enriched REE pattern and an additional enrichment in Zr and Y. Combined enrichment in MREE-HREE and other HFSE is taken as evidence that metasomatic overprint in this case was caused by a silicate melt.

MODEL

Based on experimental constraints (Green et al., 1986; Brey and Köhler, 1990; Bulatov et al., 1991) the evolution of the lithospheric mantle beneath the Slave craton has to involve an early stage of melt depletion occurring at low pressures in the spinel stability field (Stachel et al., 1998). This primary depletion event leaves behind a residue with high Cr/Al ratio, as reflected in the Cr rich compositions observed for many garnets in concentrates, peridotite xenoliths and as inclusions in diamonds from the Slave. In a second stage this depleted mantle residue was stacked beneath the early Slave craton and successively re-enriched in major and trace elements. The elevated geothermal gradients derived from separate (i.e. non-touching) inclusions and the inferred "rapid" cooling after diamond formation may relate diamond precipitation and mantle metasomatism to short lived thermal perturbations (magmatic intrusions). The sublithospheric (lower mantle) diamond suite may have been emplaced in the cause of such intrusive events.

REFERENCES

Brey, G.P. and Köhler, T., 1990. Geothermobarometry in four-phase lherzolites II. New thermobarometers, and practical assessment of existing thermobarometers. J. Petrol., 31: 1353-1378.

Bulatov, V., Brey, G.P. and Foley, S.F., 1991. Origin of low-Ca, high-Cr garnets by recrystallization of low-pressure harzburgites. 5th Int. Kimberlite Conf., Extended Abstracts, CPRM Spec. Publ., 2/91: 29-31.

Chinn, I.L., Gurney, J.J. and Kyser, K.T., 1999. Diamonds and mineral inclusions from the NWT, Canada, 7th Int. Kimberlite Conf., Cape Town, not paginated.

Davies, R.M. et al., 1999. Diamonds from the deep: pipe DO-27, Slave Craton, Canada. In: J.J. Gurney, J.L. Gurney, M.D. Pascoe and S.H. Richardson (Eds.), Proc. 7th Int. Kimberlite Conf., Capetown, 148-155.

Green, D., Falloon, T., Brey, G. and Nickel, K., 1986. Peridotite melting to 6Gpa and genesis of primary mantle-derived magmas. 4th Int. Kimberlite Conf., Perth, Extended Abstracts: 181-183.

Griffin, W.L. et al., 1999. Layered mantle lithosphere in the Lac de Gras area, Slave Craton: Composition, structure and origin. J. Petrol., 40(5): 705-727.

Heaman, L.M., Kjarsgaard, B.A. Timing of eastern North American kimberlite magmatism: continental extension of the Great Meteor Hotspot track? Earth Planet. Sci. Lett., 178: 253-268

Harley, S., 1984. An experimental study of the partitioning of iron and magnesium between garnet and orthopyroxene. Contrib. Min. Pet., 86: 359-373.

Liu, L.G., 1978. A new high pressure phase of spinel. Earth and Planet. Sci. Lett., 41: 398-404.

O'Neill, H., 1980. An experimental study of the iron-magnesium partitioning between garnet and olivine and its calibration as a geothermometer: corrections. Contrib. Min. Pet., 72: 337.

O'Neill, H. and Wood, B., 1979. An experimental study of the iron-magnesium partitioning between garnet and olivine and its calibration as a geothermometer. Contrib. Min. Pet., 70: 59-70.

Pokhilenko, N.P. et al., 2001. Crystalline Inclusions in Diamonds from kimberlites of the Snap Lake area (Slave craton, Canada): New evidences for the anomalous lithospheric structure. Dokl. Earth Sci., 380(7): 806-811.

Pollack, H. and Chapman, D., 1977. On the regional variation of heat flow, geotherms, and lithospheric thickness. Tectonophysics, 38: 279-296.

Ryan, C., Griffin, W. and Pearson, N., 1996. Garnet geotherms -- pressure-temperature data from Cr-pyrope garnet xenocrysts in volcanic rocks. J. Geophys. Res., 101, B3: 5611-5625.

Sobolev, N., Lavrentev, Y., Pokhilenko, N. and Usova, L., 1973. Chrome-rich garnets from the kimberlites of Yakutia and their paragenesis. Contrib. Min. Pet., 40: 39-52.

Stachel, T., Viljoen, K.S., Brey, G., Harris, J.W., 1998. Metasomatic processes in lherzolitic and harzburgitic domains of diamondiferous lithospheric mantle: REE in garnets from xenoliths and inclusions in diamonds. Earth Planet. Sci. Lett., 159: 1-12

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